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Measurements of $\mathcal{R}(D^*)$ at LHCb

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Summary. — Lepton universality violation would represent a signal of physics beyond the Standard Model. Semileptonic decays of beauty mesons in third-generation leptons are particularly interesting, since anomalies have been observed in the measurement of their Branching Ratios. This contribution reports on the measurements of the observable $\mathcal{R}(\mathcal{D}^*) = \mathcal{B}(\mathcal{B}' \to \mathcal{D}^{*-}\tau^+\nu_\tau)/\mathcal{B}(\mathcal{B}' \to \mathcal{D}^{*-}\mu^+\nu_\mu)$ performed at LHCb using both leptonic and hadronic decay channels of the τ lepton.

1. – Introduction

In the Standard Model (SM) of particle physics the electroweak couplings of the gauge bosons to the leptons are independent of their flavour, a property known as lepton universality (LU), so the observation of LU violation would be a clear signal of physics processes beyond the SM.

The branching fractions ratio

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}\left(B^0 \to D^{(*)-}\tau^+\nu_\tau\right)}{\mathcal{B}\left(B^0 \to D^{(*)-}\mu^+\nu_\mu\right)} \tag{1}$$

represents a sensitive probe for LU violation.

The combination of the measurements of $\mathcal{R}(D^{(*)})$ already performed by BaBar [1], Belle [2-4] and LHCb [5] Collaborations shows a discrepancy of about 4σ with respect to the values of $\mathcal{R}(D^{(*)})$ calculated within the SM [6]. All of these measurement have been performed reconstructing the τ lepton through the leptonic decay $\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$(1).

(1) Charge conjugated decay modes are implied throughout the document.

2. – Measurement with the $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\bar{\nu}_\tau$ channel

In LHCb a measurement of $\mathcal{R}(D^*)$ using the hadronic τ decay has been performed. The signal chosen for this analysis is $B^0 \to D^{*-}\tau^+\nu_\tau$, where the D^{*-} is reconstructed through the $D^{*-} \to \bar{D}^0(\to K^+\pi^-)\pi^-$ decay chain, while the τ lepton is reconstructed through the $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\bar{\nu}_\tau$ decay. The chosen normalization channel is $B^0 \to D^{*-}\pi^+\pi^-\pi^+$, because most of the systematic uncertainties cancel out in the efficiency ratio, since signal and normalization have the same final state.

The most dominant background consists of inclusive decays of b-hadrons to $D^*3\pi X$, where the three pions come promptly from the b-hadron decay vertex. Since the τ decay vertex is reconstructed with good resolution, it is possible to suppress this kind of background requiring the τ vertex to be downstream, along the beam direction, with respect to the B vertex with a 4σ significance.

The background surviving the first selection is mainly due to double-charmed B decays, since their topology is very similar to the signal one. In order to discriminate this background from signal, a set of variables is used: variables computed with two partial reconstruction techniques, one in signal hypothesis and the other in background hypothesis; isolation variables; variables related to the 3π system dynamics. These variables are used as input to train a boosted decision tree (BDT).

The partial reconstruction in signal hypothesis allows to compute the squared $B-D^*$ transferred momentum q^2 and the τ decay time with a sufficiently good resolution to maintain separation between signal and background.

Three-dimensional shapes of q^2, τ decay time and BDT output are extracted from simulated and data-driven control samples which represent the various contributions in data. In order to extract the signal yield, the three-dimensional shapes are used to perform an extended maximum-likelihood template fit on data in the high-BDT region.

To select normalization events, the τ vertex requirement is reversed, *i.e.*, the τ vertex is required to be upstream with respect to the D^0 vertex with a 4σ significance. The normalization yield is obtained by fitting the $D^*3\pi$ invariant mass distribution.

3. – Results

The result of the measurement is

$$\mathcal{R}(D^*) = 0.285 \pm 0.019(\text{stat}) \pm 0.025(\text{syst}) \pm 0.014(\text{ext}), \tag{2}$$

and has the best statistical precision among all the measurements of $\mathcal{R}(D^*)$ performed so far. It is higher than the SM calculation and consistent with it within one standard deviation.

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